Model Test of Base Mat Uplift of Nuclear Reactor Building
Part 1: Laboratory Test

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ABSTRACT

The nuclear reactor building is required to be constructed on a bedrock stratum in Japan. According to the seismic analysis for the structural design, it is indicated that the base mat uplift occurs partially. The tests, therefore, were performed to elucidate the uplift phenomenon of the reactor building through fundamental experiments which consist of two parts: the laboratory test using the shaking table and the field test using the exciter and hydraulic jack.

This paper describes the detail of the laboratory test. Based on test and analytical results, estimations on the following subjects have been made: (1) input level and contact ratio, (2) contact ratio and response spectrum and (3) effects due to the simultaneous horizontal and vertical excitation.

In conclusion, the validity of the present design method has been ascertained.

1 INTRODUCTION

Analytical and experimental researches have been conducted concerning the uplift phenomenon of the rigid structures such as the reactor building.

However, most of such researches consist of laboratory tests using small scale models. Therefore, the laboratory test and the field test using large scale models were conducted. Of these tests, this paper describes the results of the laboratory test and subsequent analysis, and the results of the field test will be presented at the 11th SMiRT Conference.

2 TEST METHOD

The following two tests were conducted to obtain fundamental data, focusing on the evaluation of uplift phenomenon rather than on the similarity between the model and the actual building.

Small-size shaking table test was carried out using an electric shaking table. Sinusoidal wave was adopted as an input motion in a horizontal direction. Two soil models made of silicone rubber were simulated soft and hard soil conditions. The structure model was made of steel.

Large-size shaking table test was carried out using the oil-pressure type shaking table. Sinusoidal wave and random wave were adopted as input motions either in a horizontal direction or in simultaneous horizontal and vertical directions. The soil model was made of silicone rubber as same as the small-size shaking table test. The structure model was made of concrete.

Their configurations are shown in Fig.1. Measurements are the accelerations, displacements of test models, earth pressure in soil, and contact ratio using accelerometers, displacement transducers, earth pressure gauges, and contact gauges respectively.

3 TEST RESULTS

3.1 Small-size shaking table test

1) Test for the characteristics of soil-structure system model

Excitation tests for the low level constant acceleration were performed to obtain vibration characteristics of soil-structure system model under no-uplift condition where contact ratio was 100%.

Test results are tabulated in Table 1.

2) Dynamic uplift test using soft soil model

Test results of Case 1, where the weight is located at the top of the structure on the soft soil, are as follows: The excitation frequency uses 9.94Hz which is the primary resonance frequency for the soil-structure system model, and input acceleration levels were 6.4-261.1gal. The relation between input acceleration levels and contact ratio is given in Table 2. Fig.2 shows the response waves when the contact ratio is about 40%. In this figure, the measured horizontal acceleration waveform presents rounded(flattened) peak pattern and the vertical acceleration has high frequency components when the uplift is occuring.

3.2 Large-size shaking table test

1) Test for the characteristics of soil-structure system model

The excitation test for the low level constant acceleration were carried out to look into the vibration characteristics of the soil-structure system model under no-uplift condition where contact ratio was 100%.

Test results are tabulated in Table 3.

2) Dynamic uplift test

Several kind of waves, such as El centro, White noise, Golden Gate, Artificial and Sinusoidal waves, were adopted as input motions. The results of El centro wave excitation are representatively described as bellow: Fig.3 shows acceleration waveforms when the input acceleration is 243gal. The contact ratio is 26% and peaks of acceleration waveform are flattened. The response spectra subjected two levels of input accelerations(47gal and 220gal) are put into comparison in Fig.4. In the case of 220gal input acceleration which brought about the uplift, the peak point is shifted toward the long period and short period components tend to increase, compared with the case of 47gal input acceleration.

Next step is to study how the structure response spectrum varies when the horizontal and vertical input motions are simultaneously applied. Fig.5 shows that the vertical input motion scarcely affect the horizontal response spectrum of the structure. The response spectra of analytical results using a sway-rocking model, also shown in Fig.4 and Fig.5, agree well with the test results.

4 ANALYSIS AND CONSIDERATION OF THE TEST RESULTS

The following relationships which are common factors in the test results were analyzed and considered.

1) Input condition and the acceleration level at initial uplift

The acceleration levels at the initial uplift occurred are tabulated in Table 4 from the results of the test and the response analysis using a sway-rocking model.

The acceleration at the initial uplift in the analysis was determined as an input acceleration when the maximum overturning moment, which was based on a linear response analysis, was equivalent to the uplift marginal moment (M_0=WL/6) assuming the earth pressure distribution being triangular. It is found that the uplift occurs most easily in the case of the sinusoidal wave excitation, whereas it causes hardly in the case of White noise wave excitation.

2) Relation between contact ratio and overturning moment

The relation between the overturning moment M and the contact ratio η is described in Fig.6 in comparison with the case where the earth pressure distribution is assumed to be triangular and the test data. The solid line in these figures shows the relation $M - \eta$ which is derived on the assumption as

$$\eta = (3 - M/M_0) / 2 .$$

These figures show that contact ratio defined from the test results is slightly larger than that defined from the above equation.

3) Response spectra in short period region

In shorter period region than the fundamental resonance period region around 0.15 second, the response spectra are amplified as the uplift phenomenon develops from Fig.4. Fig.7 makes it easy to understand the above tendency. At the top of the structure and the gravity center of the base mat, the response spectrum ratios at one half and one third(about 0.07 and 0.05 second) of the resonance period are predominantly amplified.

5 CONCLUSIONS

The followings are concluded, summing up the entire test and analytical results:

1) The condition of initial base mat uplift is significantly influenced by the spectrum characteristics of the applied seismic wave. In the other words, it was found that the uplift easily occurs for the input of the seismic wave with spectrum characteristics containing resonance frequency of soil-structure system model.

2) As the input acceleration increases, the contact ratio decreases, and the response acceleration magnification also turns to lower, while the resonance frequency of the soil-structure system model shifts toward the longer period.

3) It is revealed that the response spectra tend to grow for the short period components such as one half or one third of the fundamental resonance period with the decreasing of the contact ratio.

4) It is found that the simultaneous horizontal and vertical excitation has little influence on the characteristics of uplift phenomenon, comparing with the horizontal excitation only.

The above conclusions has been considered in the present design method, thereby the validity of the present design method could be ascertained.

6 ACKNOWLEDGEMENT

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Table 1 Resonance frequency and damping factor of soil-structure system model (small-size shaking table test)

CASE	1 ·soft soil ·weight height:top		2 ·soft soil ·weight height:mid.		3 ·hard soil ·weight height:top		4 ·hard soil ·weight height:mid.	
MODE No.	resonance frequency (Hz)	damping factor (%)	resonance frequency (Hz)	damping factor (%)	resonance frequency (Hz)	damping factor (%)	resonance frequency (Hz)	damping factor (%)
1	9.94	2.32	12.30	2.76	11.60	2.15	15.25	2.62
2	——	——	46.80	——	——	——	——	——

Table 2 Relationship between input acceleration and contact ratio (small-size shaking table test)

Input acceleration (gal)	Response acceleration at base mat bottom (gal)	Contact ratio (%)
6.4	12.8	100.0
42.3	35.0	78.5 - 88.0
93.8	98.6	69.0 - 78.5
136.6	159.0	59.5 - 69.0
179.7	214.8	50.0 - 59.5
220.6	271.8	40.5 - 50.0
261.1	325.9	31.0 - 40.5

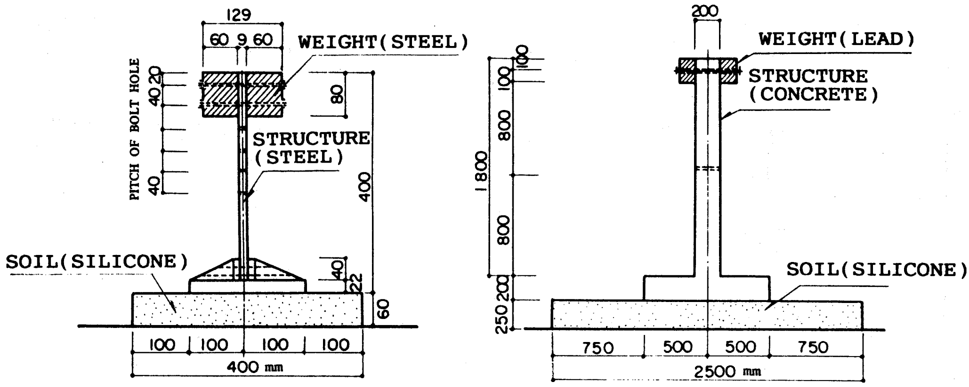
Table 3 Resonance frequency and damping factor of soil-structure system model (large-size shaking table test)

CASE	1 Additional weight is located bot. of model		2 Additional weight is located mid. of model		3 Additional weight is located top of model	
MODE No.	resonance frequency (Hz)	damping factor (%)	resonance frequency (Hz)	damping factor (%)	resonance frequency (Hz)	damping factor (%)
1	10.2	6.29	8.9	6.57	6.3	4.47
2	27.3	2.88	27.0	2.33	25.2	2.31

Table 4 Comparison with test and analytical results for input acceleration at initial uplift (large-size shaking table test)

Input wave	Test	Linear response analysis	
	Input acceleration at initial uplift (gal)	Input acceleration at initial uplift (gal) note1)	Maximum overturning moment (ton·m) note2)
White noise wave	116.1	97.9	0.331
El centro wave	84.1	70.9	0.457
Artificial seismic wave	52.5	53.2	0.609
Golden Gate wave	78.7	45.6	0.712
Sinusoidal wave(6.3Hz)	44.1	43.6	0.743

note1) Input acceleration(α) at initial uplift is determined by next equation.
$\alpha = 100(\text{gal}) \times M_0 / (\text{Maximum overturning moment})$; $M_0 = 0.324(\text{ton·m})$
note2) Input acceleration is 100 gal.



(a) Model for small-size shaking table test

(b) Model for large-size shaking table test

Fig.1 Configuration of models

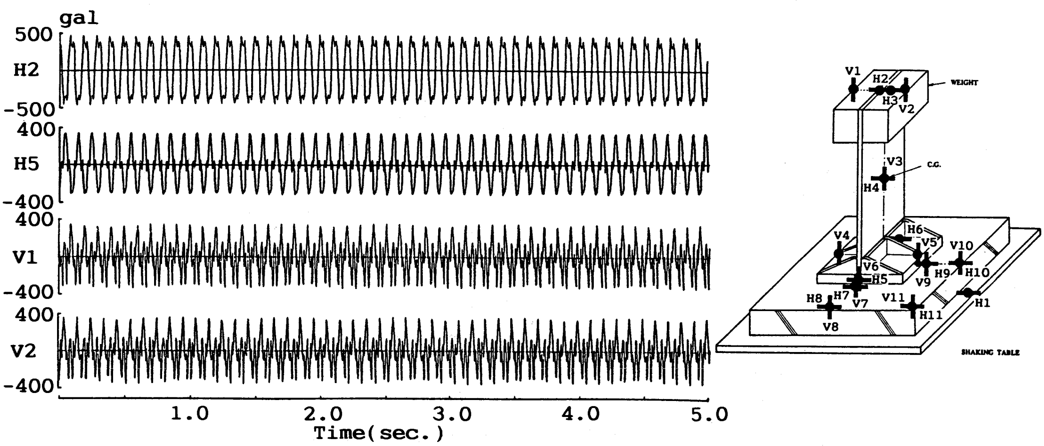


Fig.2 Time history of measured acceleration
(Maximum input acceleration:261gal,Exciting frequency:9.94Hz
Small-size shaking table test)

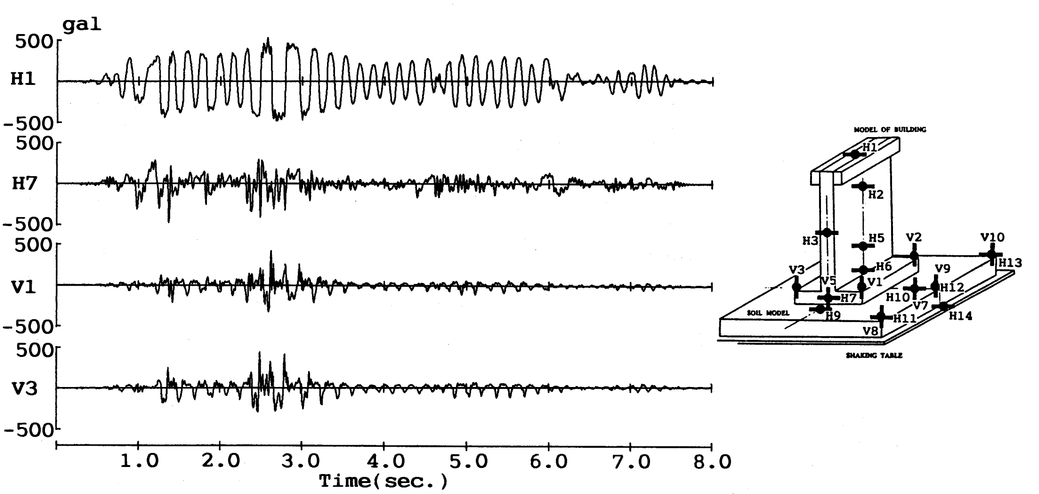


Fig.3 Time history of measured acceleration
(Maximum input acceleration:243gal,El centro,Time scale:1/2
Large-size shaking table test)

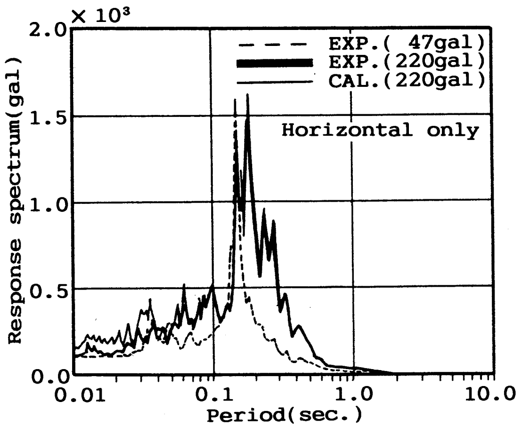


Fig.4 Acceleration response spectrum
(Response acceleration is normalized to 100gal, El centro,h=1% Large-size shaking table test)

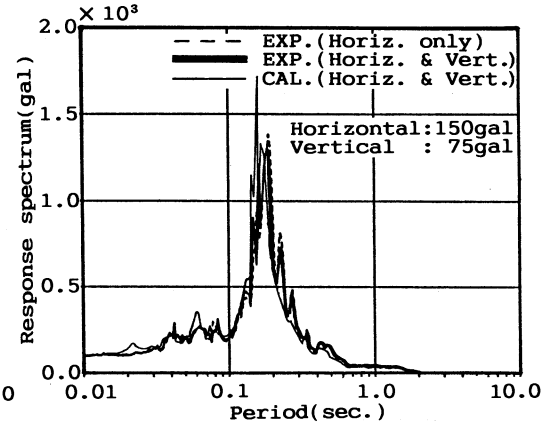
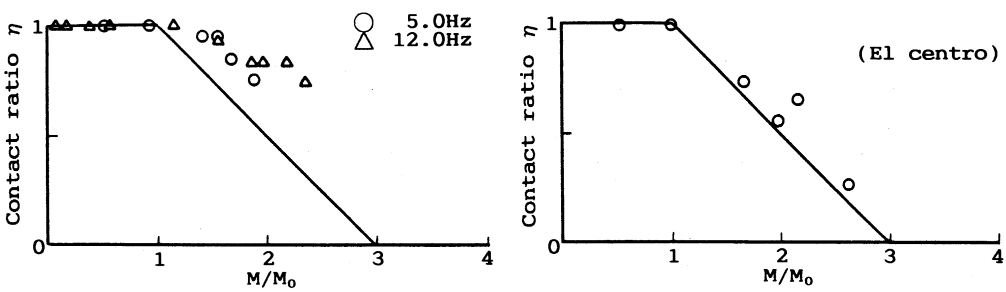
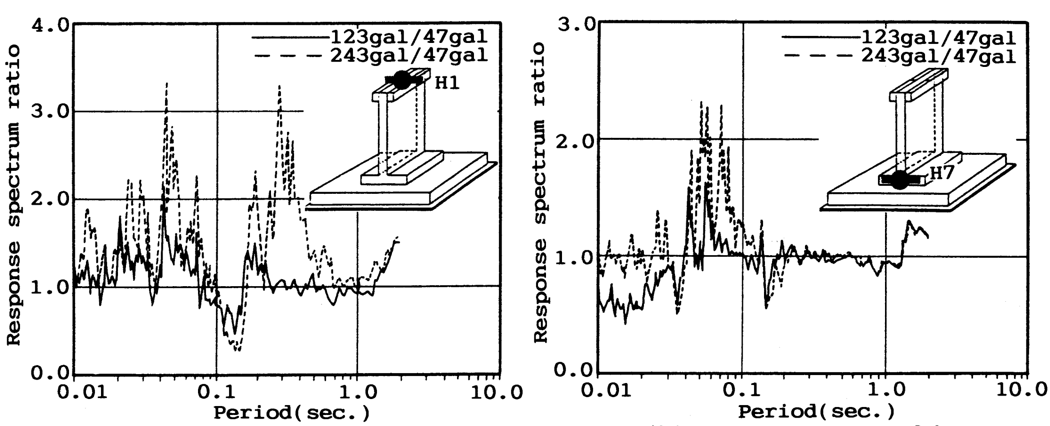


Fig.5 Acceleration response spectrum
(Response acceleration is normalized to 100gal, El centro,h=1% Large-size shaking table test)



(a) Small-size shaking table test (b) Large-size shaking table test

Fig.6 Contact ratio and overturning moment



(a) Top of structure (b) Gravity center of base

Fig.7 Ratio of acceleration response spectrum
(Large-size shaking table test,El centro)